International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 3, Jun 2018, 1-12

DESIGN AND PERFORMANCE EVALUATION OF POLYHEDRAL SWEPT BACK HIGH WING CHUCK GLIDER FOR BETTER L/D RATIO

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ABSTRACT

"It's not flying its falling in style." The chuck gliders are the ones which do not require any kind of thrust force since these do not have any mechanical or electrical power supply to it. For flying of such gliders, the main focus must be given towards design, material selection and the aerodynamic forces acting on it. Thus, it is required to have a design, which can have an optimum lift-to-drag ratio with balancing wing loading. These are main performance parameters, which needs to be considered in order to make an efficient glider. With the preset constraints of maximum wingspan of 50cm, as enlisted in competitive events across the globe, the glider ought to be designed, manufactured and analyzed having good range and endurance, to level up the competitions. For the designing factor, it is chosen to have high, polyhedral and elliptical wing configuration with a backward sweep of 9 – 12 degrees. The material chosen for the chuck glider is balsa wood. Along with these main wing configurations, empennage section is designed to have dihedral horizontal stabilizers and a slender fuselage of 65cm. The geometrical CG of the glider is fixed at 25% of the fuselage length; further balanced using clay. The validated analysis of the glider was carried out in the calibrated sub-sonic Wind Tunnel and the values of lift, drag and pitching moment were tabulated using 3 point balance at various speeds in the range 0 – 25 m/s. Using this optimum lift-to-drag ratio was determined, leading to optimized range and endurance of glider.

KEYWORDS: Chuck Gliders, Performance Parameters, Polyhedral and Elliptical Wing, Balsa Wood, 3 – Point Balance, Lift-to-Drag Ratio, Glide Range & Endurance

Received: Mar 02, 2018; **Accepted:** Mar 23, 2018; **Published:** Apr 20, 2018; **Paper Id.:** IJMPERDJUN20181

Original Article

INTRODUCTION

A glider is the airplane which penetrates through the air and glides like a bird, without any external source to serve the world. The special kind of dreamers, dreamed different gliders, which changed the era of past, present, and future, made it working fuel for this chuck glider, to be an enlightened innovator. All the general gliders have large span and a very the large glide ratio but the chuck gliders are small with less glide ratio, defining a scope for an impeccable glider. Aerodynamics for people can be understood by balsa gliders, making the cheapest way to impromptu flying sailors. This is how the performance of the glider ought to be understood by imagination.

One such dreamer named **J H Maxwell [1]** proved using balsa glider, it's the best material to be used for making a glider, since it can be finished with smooth surface texture and it has awesome strength when used as a build-up material. During the launch, the joint of the fuselage to wing needs to be strong to prove the effect of lusty loads wrong. Thickness of tail surfaces must be 1/16th inches, while for fuselage it needs to be 1/8th inches.

Initially, the glider needs to be smoothened with the finest grade of sandpaper, filled with balsa powder in the gaps well rubbed off with a finer grade to make it glossier.

From the paper on **Estimating Oswald Factor (e) From Basic Aircraft Geometrical Parameters by Hamberg University of applied sciences [2]** mentioned elliptical planform wing has the value of **e** as **1**; because of the constant downwash δ becomes 0 and thus $(1+\delta)^{-1}$ becomes 1 leads to reduction in $C_{D,i}$ by the equation $C_{D,i} = (C_l)^2/(\pi e AR)$ further increasing lift. This is the calculating feature, modifying the existing character of our chuck glider. Even in the plans provided by **the scientist of NASA and SAE [3]**, it is advised for the gliders to have a high wing with the elliptical wingspan since it can optimize glide ratio. Also, it's beneficial for having the good lift with the minimal amount of drag generation. **RC Groups [4]** mentioned that the high wing leads to decrease in induced drag due to fuselage by making the air turbulent, near to leading edge only for 1/4th of the chord of LE; thus area affected of the fuselage is less, but in mid or low wing; the turbulence created approach about the distance of the root of the chord leading to more area to be affected. Explanatory authorizations and authentications by **HAW Hamburg University in their paper and by S Andrew Ning & Ilan Kroo of Stanford University [2,5]** said that with the deployment of dihedral or polyhedral angles the roll stability of the aircraft increases and it can withstand the sudden gust loads acting on it. Even giving a little washout and twist to the wing can also help to reduce the effect of trailing edge vortices and can increase the aerodynamic stability of the aircraft. It also can resist the effect of thermals in the warm environment and can get stabilized accordingly to the static equilibrium. So it's advised to go for a polyhedral or dihedral angle.

MAV literature survey by **Defense Advanced Research Projects Agency (DARPA) [6,7]** explains a micro air vehicle (MAV) to have a size of less than or equal to 15cm or 6 inches in length, width, or height. The development of micro air vehicles gained popularity in the 1980s for model aircraft and RC planes in the 1990s. The possibility of such vehicles for military use was raised by the RAND Corporation in 1992. Few of the miniature unmanned MAV have VTOL capability like Honeywell T-Hawk with catapulted launch systems and for a change, Aerovironment Wasp can be hand launched. The gliders ultimately attracted to the concept of the competition because of its versatile use. A paper titled "Development of Deployable Wings for Small Unmanned Aerial Vehicles Using Compliant Mechanisms" written by Steven Landon of Brigham Young University told for the deployable wing concept which is one of the most helpful resources. All the above researchers and the efforts of the people all around encouraged to get to the optimized design of the chuck glider defining perfect high, elliptical wing configuration. The polyhedral angles further add to attain roll stability. Other performance parameters such as glide ratio, 5lift-to-drag ratio, and balanced wing loading were optimized. This glider has slender fuselage to increase the endurance. To increase its range backward sweep changes the aspect of innovators. People use the different approach of designing in different models but this paper took it in whole and applied to create miracles.

METHODOLOGY

1. Theoretical Background

1.1. High Wing

The high wing is the one which is mounted on the upper fuselage, shoulder wing is a type of high wing in which the wing is mounted on the projection above the top of the main fuselage.

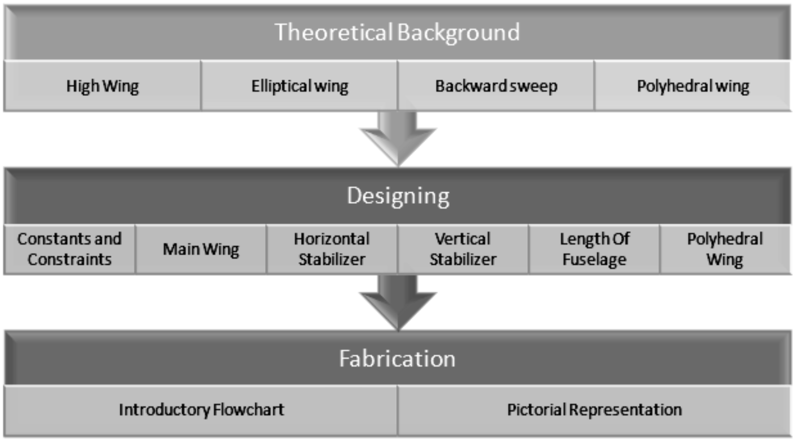

Figure 1: Flowchart of Design and Development of Chuck Glider

Criterias for Choosing High Wing

- It is aerodynamically stable than low and mid wing aircraft.
- The resultant lift generated at the wing center of lift is higher for high wing aircraft compared with mid wing and low wing aircraft.
- Roll and yaw stability are more for glider having the high wing.
- The induced drag created due to fuselage decrease as we use the high wing because in high wing the air becomes turbulent only by ¼ th of the leading edge and there is a less area to be affected of the fuselage. While in mid- wing aircraft the turbulence creation is about the distance of the root of the chord and because of the location a lot more area of the fuselage comes into play for turbulence to act on and thus it increases induced drag and decreases the efficiency of the glider.
- High wing aircraft are easy to chuck and there are less chances of the accident while slinging with the help of a catapult.
- It causes low damage for a low wing and mid wing aircraft when it lands as it strikes the ground.

1.2. Elliptical Wing

The elliptical wing is that kind of a wing whose top view along its span is of an elliptical shape from tip to tip including fuselage.

Criteria for Choosing Elliptical Wing

- It is aerodynamically efficient.
- The magnitude of the lift generated by the elliptical wing is of the highest amount.
- The induced drag is very less and thus lift is more.
- By the thin airfoil theory and Kutta - Jokwoski theorem, the elliptical planform wing can produce lift, since the value of the induced drag along elliptical span is very less with respect to the normal game and thus lift increases.
- Since the induced drag decreases for the elliptical wing the value of circulation below the surface of wing

increases and to get the perfect elliptical lift distribution it is recommended to have elliptical planform over the wing now since Kutta - Jokwoski says **ϒα L** which indicates circulation varies linearly with lift.

- Also C(y) [CHORD] = L'(y)/ $q_\infty C_{1,}$ where: L is lifted in N, q_∞ is dynamic pressure in Pa and C_1 is the coefficient of lift. The above relation says the chord must vary elliptically along the span which is the condition given by Prandtl lifting line theory to show elliptical wing planform.
- The wing with elliptical planform has constant downwash and thus it makes it aerodynamically stable; since the varying downwash can create more induced drag and the efficiency decreases.

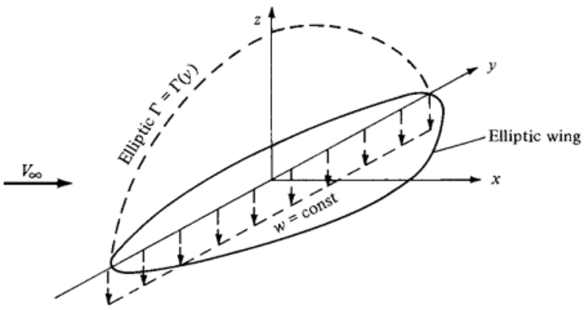

Figure 2: Prandtl Lifting Line Theory [8]

1.3. Backward Sweep

The wings sweep back provides aerodynamic stability to the conventional tail-less empennage sections like for the Dunne Aircrafts which has main wing sweeping back from root to the tip. The backward sweep wings are the wings which have some offset from the wing tip side, towards backward, at some distance; while wing root is at the same position.

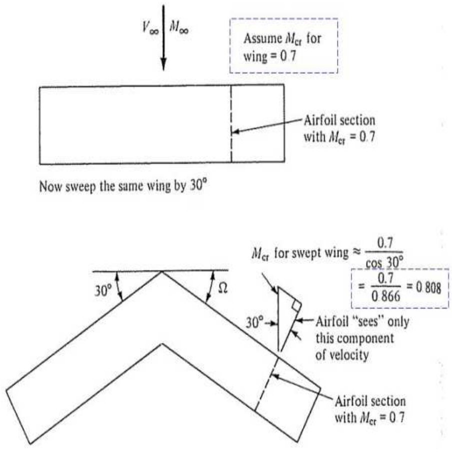

Figure 3: Swept Wing Effect [9]

Criteria for Choosing Backward Sweep

Since all the chuck gliders are subsonic so to reduce the induced drag and increase of M_{cr} (Critical match number) up to some extent, it is required to have swept back wings.

∴ Initially when $M_{cr} = M_\infty$ when above the surface of airfoil taking

$M = 1$ (1)

Now, $M_\infty = M_{cr} \cos \Omega$

Where Ω is the sweep angle

Considering (1) if $M_{cr} = M_\infty$

Then new $M_{cr} = M_{crn} = M_{cr} / \cos \Omega$ (2)

That is from the previous M_{cr} the new M_{crn} is increased to reduce induced drag because when M_∞ approaches M_{cr} the drag increases so M_{cr} needs to be increased which is done with swept back wings.

- The value of the drag divergence is delayed with higher match numbers.

$$C_P(min) = \frac{C'_P(min)}{\sqrt{1 - M_\infty^2}} \tag{3}$$

- Also on the contrary of the discussion above the induced drag is decreased, but on the increase of sweep angle, it is seen that the L/D ratio decreases as the angle are increased, so it tends to reduce the lift too. So it is just to get the optimized value of wing sweep angle to get the good lift.
- Also sweeping back the wing, stability of the aircraft increases and its behavior to the turbulent air passing through it. It maintains steady level flight by balancing CG.
- The decrease in L/D ratio leads to less altitude, but it can go large range and floats easily at lower altitude after slinging it.

1.4. Polyhedral Wing

The polyhedral wing is that wing which has an offset of wing upward at more than 2 sections and it makes a curved upward wing as shown in figure 4 to the right.

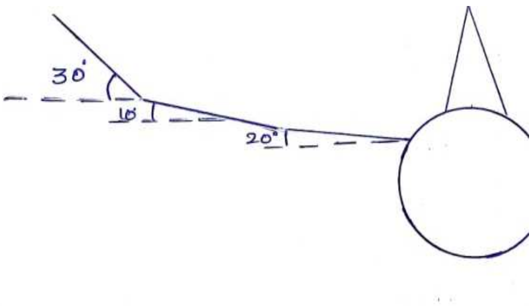

Figure 4: Representation of Polyhedral Angles

Criteria for Choosing Polyhedral Wing

- The polyhedral wing is exceptionally stable with roll and yawing and it easily gets in static equilibrium in a level flight that controls yaw and roll automatically.
- For using the polyhedral type of wing we must provide washout to the wings and use winglets or winglet like

structures and the wing tip because polyhedral wings get affected with trailing edge vortices creation and to overcome washout is required.

- The washout is one of the important factor, which is used to reduce the lift of the main wing along its span; by increasing the angle of incidence at the root of the wing and decreasing the angle of incidence, as it reaches the tip of the wing; this is done to make sure that when the wing stalls the tip stalls first and then it gradually goes to the root side.
- In a polyhedral type of wing, there are upward offset and such are affected by thermals and thus there are more chances of stalling. For avoiding it we must give washout up to a little extent to get the higher stability of the aircraft.

2. DESIGN CALCULATIONS

Slenderness Ratio

Slenderness ratio is the ratio of wingspan to the length of the fuselage for the designs of an aircraft. By increasing the slenderness of the glider we can increase its strength against the buckling of the tail section and also it resists the failure of the tail section when there is an impact from turbulence. It balances the pitching motion of the aircraft and helps to float in the air with ease.

2.1. Design Considerations

- The aspect ratio (AR): 9-10
- Wingspan constraints:50 cm from tip to tip along the surface
- Horizontal tail (Stabilizer):20-25 % of main wing area
- Vertical tail (Stabilizer):40-50 % of horizontal tail (Stabilizer) area
- Length of fuselage:75% of span (tip-tip), with slenderness:125% of span
- Wing sweep angle: 10°-15° for subsonic gliders.**[10]**

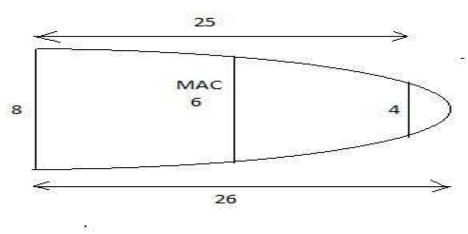

Figure 5: Right Side Main Wing with Final Dimensions

2.2. Main Wing Design

2.2.1. AR = $(S)^2/A$

We have here, AR = 9

Span = 52 cm

So, 9 = 522/A;

Wing area = 522/9 = 300.44 $cm^2 \simeq 300cm^2$.

2.2.2. Also AR = 9 = S/ C

∴ 9 = 52/ MAC

∴ MAC = 52/ 9 = 5.77cm ≃ 6cm.

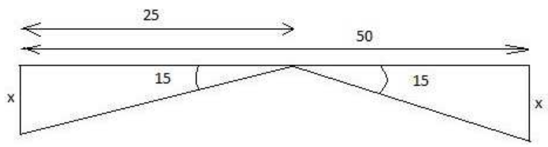

Figure 6: Swept Distance Calculation

2.2.3. Now Since Wing Sweep Angle Is 15°

∴ tan Φ = x/2

tan 15º = x/25

∴ x = 25 tan15º = 6.69 ≃ 7cm

I.e. Sweep is at 7cm distance from leading edge at the tip of wing. ∴ x' original span to be designed.

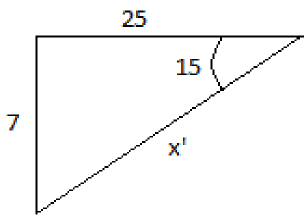

Figure 7: Swept Wing Original Span

= 25.96 ≃ 26cm.

This is the half or semi-span of the wing.

Total wing span = 26×2 = 52cm.

2.2.4. Increase in M_{cr} Due to Wing Sweep

= (1/cos 15 º) × M_{cr}

= 1.04 M_{cr}

2.2.5. MAC = 6cm

i.e. (root chord + tip chord)/2 = 6 ∴ root chord + tip chord = 12

Considering the optimized value for elliptical wing, and as the value of MAC is almost at the center of the wing so, Optimized value w.r.t. design

Root Chord = 8cm Tip Chord = 4cm.

2.3. Horizontal Stabilizer

2.3.1. Tip - Tip Area = 20-25 % Of Wing Area ∴ 0.25 × 300 = 75 Cm ^{2}

Now keeping AR same span is,

AR = $(\text{span})^2$/area ∴ Span = √AR ×Area

= √9×75

Span = 26 cm (tip - tip)

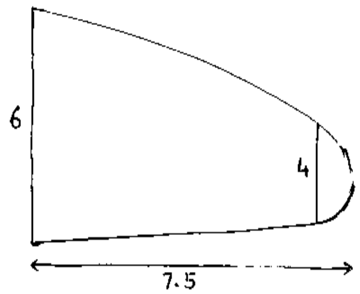

Figure 8: Right Side Horizontal Stabilizer with Final Dimensions

In same accordance chord is,

AR = Span/Chord (MAC) = 9 = 26/C, C = 2.88 cm

Using the same values of span and chord the empennage section will be too big and for the perfect glider it should have constrained empennage section. So,

For the same modifying the values of span and chord, we have

Area=span×chord ; Now let chord be 5, 75=Span×5, gives span = 7.5 cm.

2.4. Vertical Stabilizer

2.4.1. Vertical Stabilizer Area = 50 % of Horizontal Stabilizer Area = 0.5 × 75 = 37.5 Cm^2

2.4.2. AR = 9 = $(\text{Span})^2$ /Area ∴ Span = 17.37 Cm

AR = 9 = Span/Chord (mac) ∴ Chord = 2.04 cm

2.4.3. For the Design Purpose the Values of the Span and Needs to Be Modified For the Same Area,

Area = span × chord 37.5 = Span × 5.5 = 6.81 cm

2.5.1. Length of Fuselage

Length of Fuselage = 12.5 % of span = 1.25 × 50 = 65 cm

2.6. Polyhedral Angle

The angle of polyhedral are optimized using practical application.

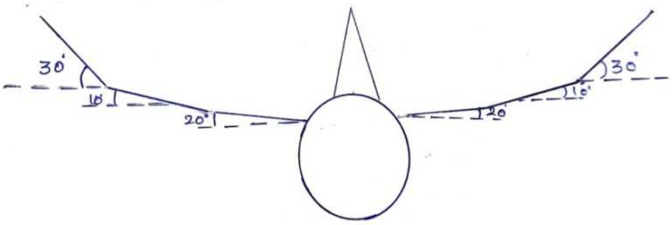

Figure 9: Optimized Polyhedral Angle Configurations

3. Fabrication

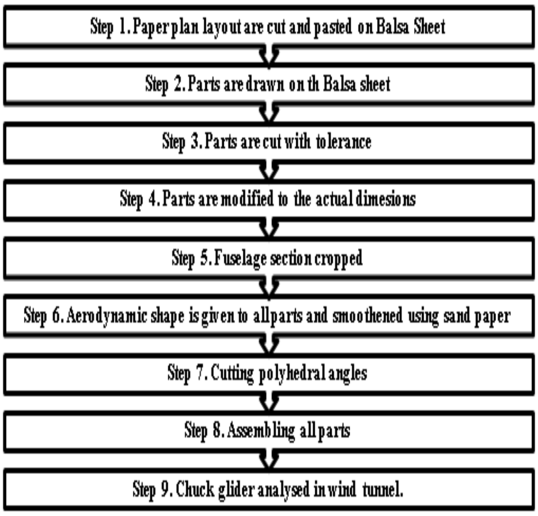

Figure 10: Flowchart of Fabrication Process

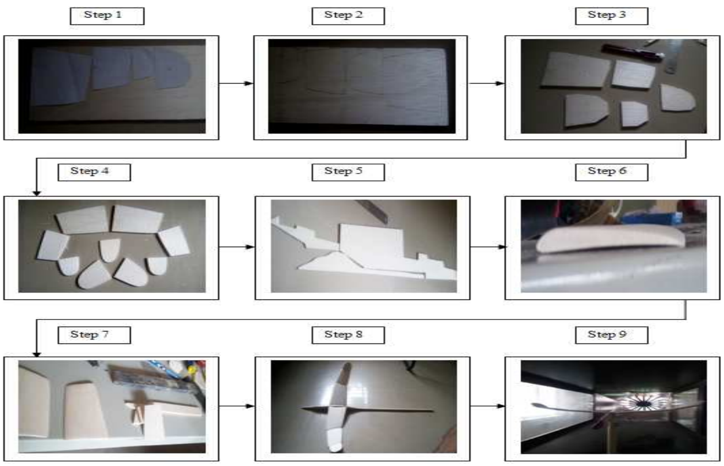

Figure 11: Fabricated Components as Per Flowchart

Figure 10 shows the flowchart in the order in which the parts are fabricated, assembled and tested in a sub-sonic Wind Tunnel. Figure 11 shows the fabricated component as per the steps listed in figure 10.

WIND TUNNEL TEST RESULTS

The Wind Tunnel testing is done for the fabricated glider using the 3 point balance method at different speeds and the value of L/D ratio is calculated. In the analysis firstly, the calibration of 3 – point balance is done. Later mounting pipe is attached to the glider to put it into the balance and it was tested for different speeds ranging from 5 to 25 m/s as

tabulated. The tests were carried out to determine the lift, drag and the pitching moments of the glider by changing the rpm with a knob. From all the results the calculations were done to determine the L/D ratio and are tabulated in table 1.

Table 1: Wind Tunnel Test Results

Serial no.	Velocity(m/s)	Lift	Drag	Pitching Moment	L/D ratio
1	5	1.3	0.4	0.1	3.25
2	10	3.1	0.7	0.1	4.43
3	15	5.5	1.5	0.4	3.67
4	21.1	9.9	2.7	0.8	3.67
5	25	14.8	3.7	1.1	4

From knowledge-based engineering the average normal wind speed in the atmosphere is in the range 12 – 15 m/s. Hence, when tested for 15 m/s we achieved L/D ratio of 3.67 which is an acceptable range for this designed model. Also, the model was practically tested for off-design high velocities at 21.1 and 25 m/s giving much greater L/D ratio of about 4. Hence, the designed glider is stable and provides better structural integrity and aerodynamic performance at both design and off –-design velocities.

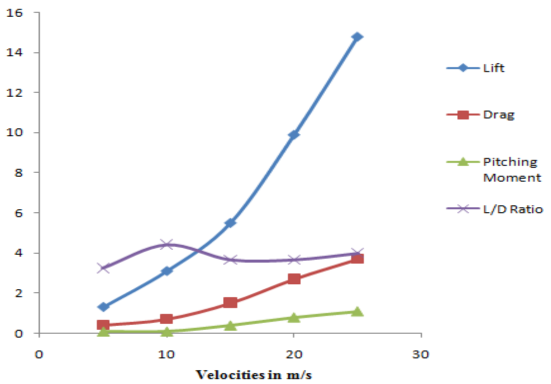

Figure 12: Variation of Lift, Drag, Pitching Moment L/D Ratio for Chosen Velocity Test Range

From figure 12 it can be observed that the lift of glider varies exponentially for the chosen velocity test ranges. Whereas the drag and pitching moment varies almost linearly in the chosen test ranges and their value is less compared to lift test results.

CONCLUSIONS

- The highest lift force obtained at 15 m/s (average test speed) is 5.5 N and its corresponding drag force is 1.5 N providing pitching moment of 0.4 which are in acceptable ranges for a glider. The achieved L/D ratio for the above test speed is 3.67.
- The chuck glider designed performs well at both design and off – designed velocity speeds in wind tunnel testing..
- The present paper describes a unique glider first of its kind having 3 stages of the polyhedral wing with elliptical planform and backward sweep features.
- When it was practically tested in a glider competition it traveled to a range of 40-45 m with an endurance of 8 – 10 seconds.

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